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ELENA – a preliminary cost and feasibility study

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Abstract

To produce dense pbar beams at very low energies (100-200 keV), a small decelerator ring could be built and installed between the existing AD ring and the experimental area. Phase-space blowup during deceleration would be compensated by electron cooling in order to obtain final emittances comparable to the 5MeV beam presently delivered by the AD.

This report describes preliminary machine parameters and layout of ELENA and also gives an approximate estimate of cost and manpower needs.

Geneva, Switzerland
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Contents

1. Introduction

ELENA (Extra Low ENergy Antiprotons) is a compact ring for further deceleration and cooling of 5.3 MeV pbars delivered by the CERN Antiproton Decelerator. The AD physics program is focused on trapping pbars in Penning traps where antihydrogen is formed after recombination with positrons. The ultimate goal is to trap and perform spectroscopy on Hbars. In today's set-up, most (99.9%) of the pbars produced are lost by the use of degrader foils to decelerate from AD ejection energy down to around 5 keV, which is suitable for trapping.

By using a ring equipped with beam cooling, high deceleration efficiency and important increases in phase-space density can be obtained, resulting in an increased number of trapped antiprotons. For the ATRAP and ALPHA experiments, improvements of 2 orders of magnitude can be expected. ASACUSA on the other hand presently use first an RFQD for deceleration to 100 keV, and then additionally an ultra-thin degrader (1 micron thick) for deceleration to 5 keV. Here, a 10-fold increase can be expected thanks to reduced transverse and longitudinal emittances.

With a circumference of about 26m, ELENA can be located in the AD hall where assembly and commissioning would not disturb current AD operation too much.

Decelerating to these low energies is certainly new and challenging, not the least for the design of the electron cooler with electron beam energy of just 200 eV.

2. ELENA overview

ELENA is to be located inside of AD Hall with a circumference as small as possible to minimize space requirements and to reduce intensity limitations due to space-charge induced tune shift. The new ring is located so that current AD operation during assembly and commissioning will be disturbed as little as possible.

AD experimental areas could be kept as they are now. But much lower beam energies require new transfer line elements and diagnostics.

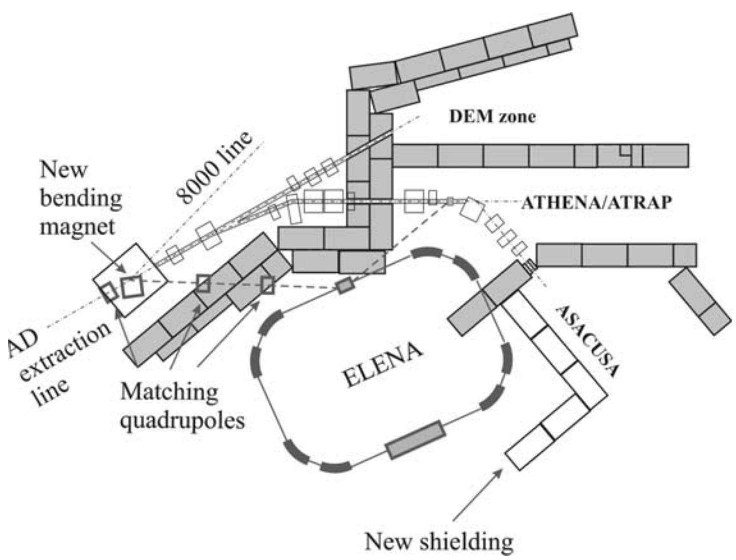


Fig.1. **ELENA placement versus existing AD beam lines.**

Ring configuration:

- Simple lattice with 8 dipoles and 8 multipoles
- One long straight section is used for beam injection and fast extraction, another is suitable for the electron cooler
- Two short straight sections are used for RF, diagnostics and other equipment

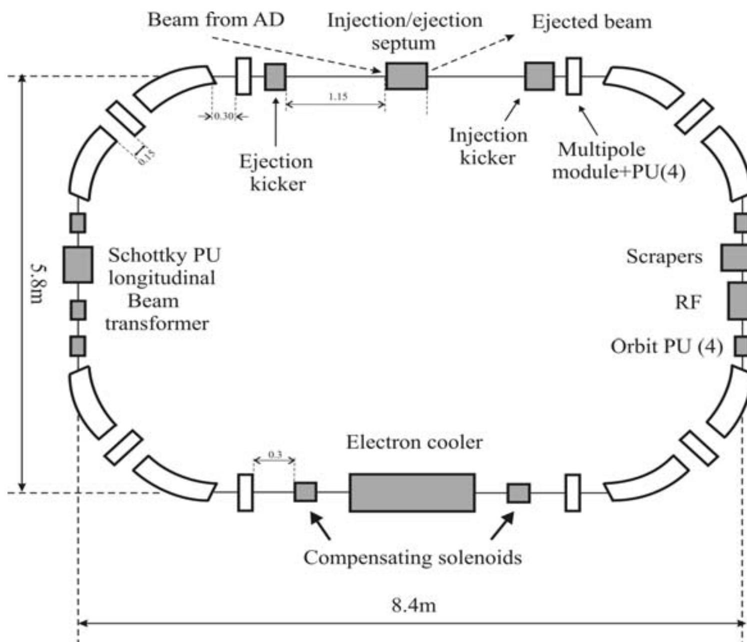


Fig.2. ELENA layout

Momentum, MeV/c	100 – 13.7
Energy, MeV	5.3 – 0.1
Circumference, m	26.062
Betatron tunes Qx/Qy	1.45/1.42
Emittances at 100 keV, π.mm.mrad, [4σ, 95%]	5 / 5
Δp/p after cooling, [4σ, 95%]	10^{-4}
Estimated Δp/p of ejected beam taking IBS into account,[4σ, 95%]	$2*10^{-3}$
Intensity limitation by space charge, bunched/coasting beam	$1.1*10^{7}$ / $2.2*10^{8}$
Maximal incoherent tune shift	0.10
Bunch length at 100 keV, m / ns	1.3 / 300
Expected cooling time at 100 keV, sec	1
Required vacuum* for Δε=0.5π mm mrad/s,Torr	$3*10^{-12}$
IBS blow up times for bunched beam* (εx,y=5π mm mrad, Δp/p=1 10-3), s	1.1 / -9.1 / 0.85
* No electron cooling is assumed	

Table 1. ELENA basic parameters

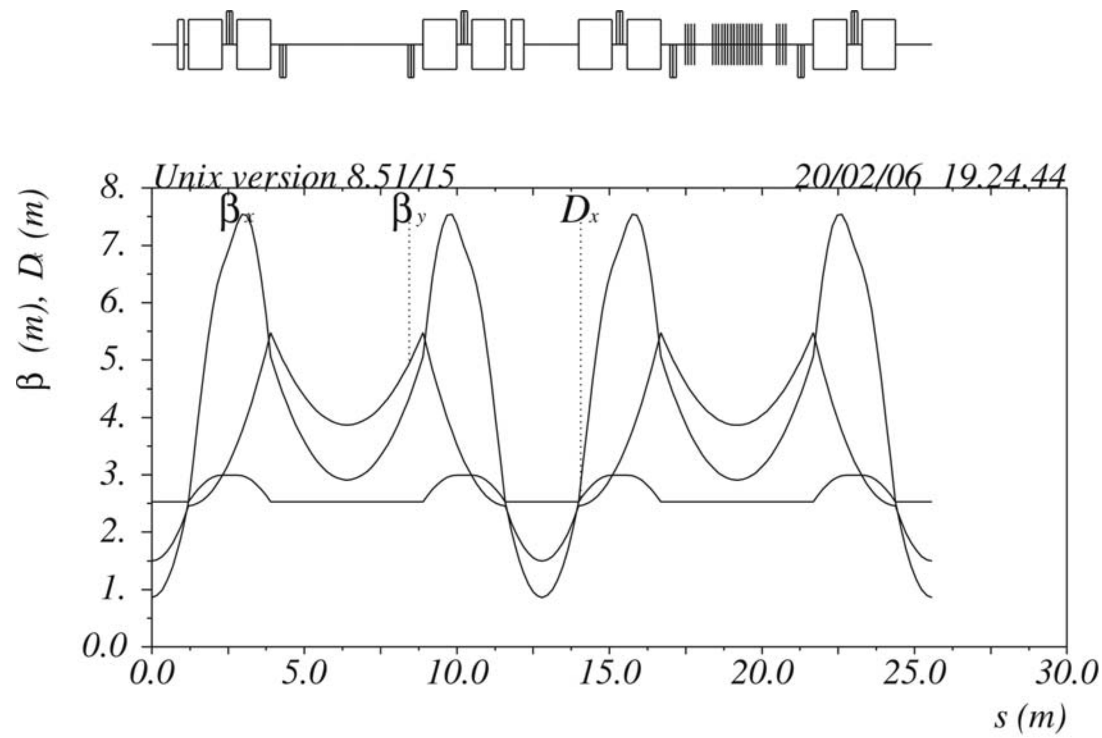


Fig.3. **Fig.3. ELENA lattice functions (electron cooler off)**

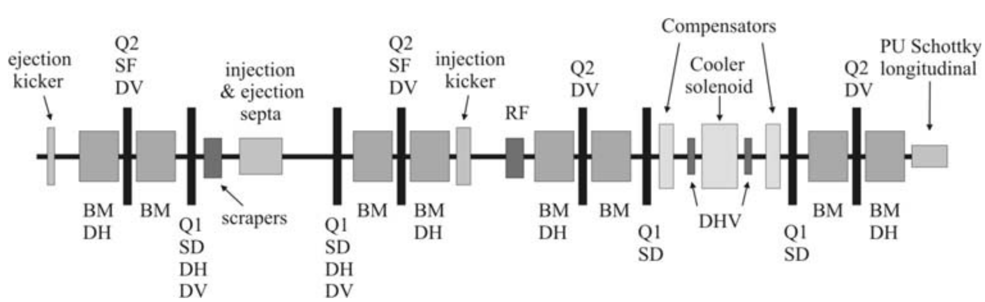


Fig.4. **Fig.4. Schematic layout of ELENA magnetic elements**

3. Ring and injection line magnets

The ring magnet system of ELENA consists of C-shaped bending magnets, quadrupoles and correcting elements. The parameters for bending magnets (totally 8 identical units) are given below in [Table 2]. A schematic representation of the edge-angle focussing is seen in [Fig. 5] Normal quadrupoles, skew quadrupoles for coupling correction, sextupoles for chromaticity correction and horizontal and vertical orbit correctors are integrated in one module [Fig. 6]. Basic parameters are given in [Table 3]. 8 of these modules will be used in the ELENA ring.

The transfer line from the existing AD will start at the BHZ8000 location with a new smaller bending magnet replacing the large BHZ8000. Furthermore, 3 quadrupoles for matching and 2 combined H/V correctors are required. See [Table 4] for parameters.

ELENA main bending magnet specifications	
Magnet field	0.23 T
Gap height	75.0 mm
Iron length	1017 mm
Effective length	1100 mm
SBdl	0.25 Tm
Momentum	100 MeV/c
B r	0.33 Tm
Deflection angle	45.0 degrees
Good field region	± 31 mm
Field homogeneity in GFR	< 0.08 %
Nominal current	192 A
Max. dI/dT	200 A/s
Magnet resistance (hot)	67.5 mOhm
Max. dissipated power	2.5 kW
Inductance	21.9 mH
Max. total voltage	17.3 V
Edge angle, degrees	0/24.1

Table 2. Ring bending magnet parameters

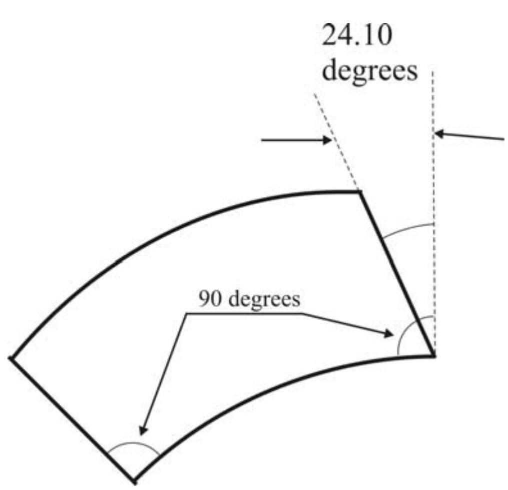


Fig.5. ELENA main bending magnet basic layout.

Number of magnets (+ spares)	8 + 1	
Magnet characteristics		
Horizontal dipole module		
Magnetic field	16.44	mT
Integrated field	4.54	mT m
Magnetic length	276.0	mm
Nominal current	37.0	A
Resistance	51.7	mOhm
Inductance	1.4	mH
Nominal voltage	1.9	V
Dissipated power	70.8	W
Vertical dipole module		
Magnetic field	12.37	mT
Integrated field	3.12	mT m
Magnetic length	252.0	mm
Nominal current	25.0	A
Resistance	90.2	mOhm
Inductance	2.2	mH
Nominal voltage	2.3	V
Dissipated power	56.4	W
Normal quadrupole module		
Gradient	191.38	mT / m
Integrated gradient	62.01	mT m / m
Magnetic length	324.0	mm
Nominal current	38.0	A
Resistance	68.3	mOhm
Inductance	1.2	mH
Nominal voltage	2.6	V
Dissipated power	98.7	W
Skew quadrupole module		
Gradient	200.91	mT / m
Integrated gradient	62.68	mT m / m
Magnetic length	312.0	mm
Nominal current	38.0	A
Resistance	77.2	mOhm
Inductance	1.2	mH
Nominal voltage	2.9	V
Dissipated power	111.4	W
Sextupole module		
Sextupole gradient	1.50	T / m^2
Integrated sextupole gradient	0.51	T m / m^2
Magnetic length	339.0	mm
Nominal current	11.0	A
Resistance	359.6	mOhm
Inductance	3.1	mH
Nominal voltage	4.0	V
Dissipated power	43.5	W
Dimensions		
Aperture diameter	128	mm
Total magnet weight	96	kg
Total magnet length	420	mm
Iron core outer diamater	267	mm

<u>Table 3.</u> Ring multipole magnet parameters

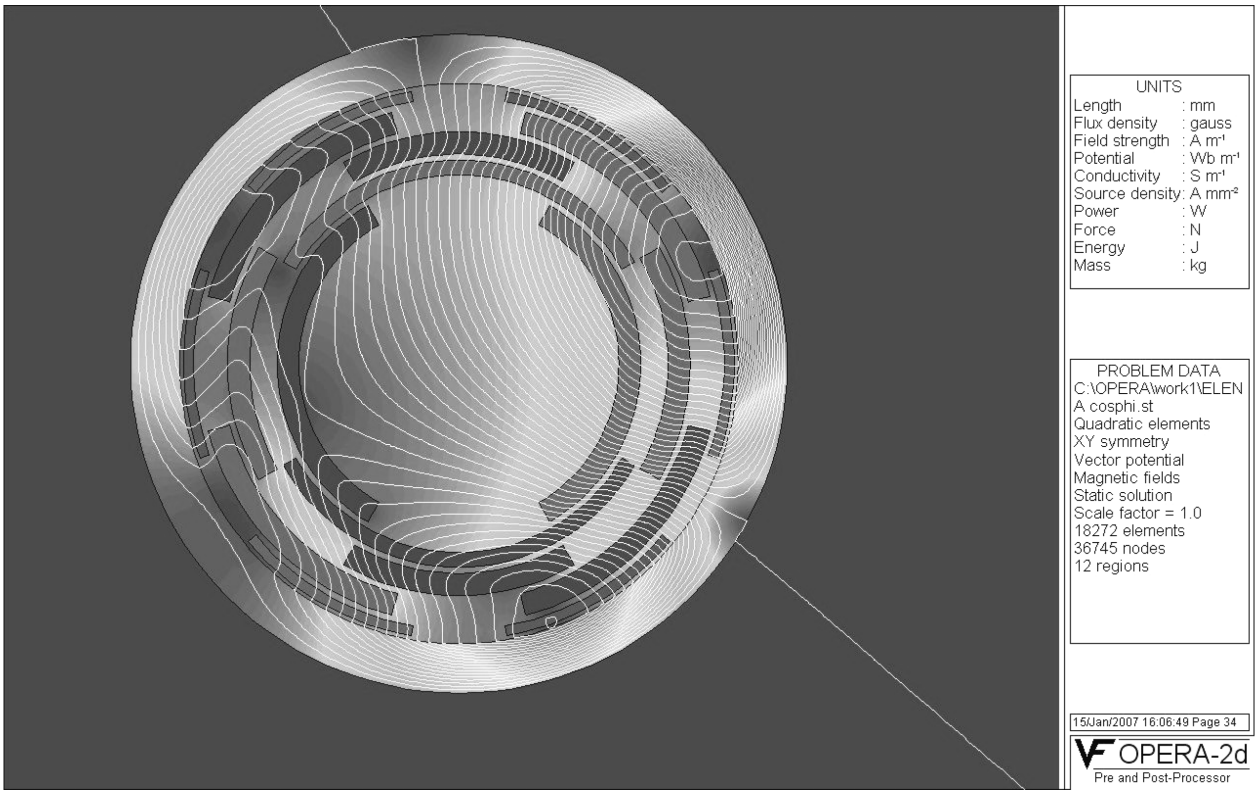


Fig.6. **Ring multipole schematic layout**

Injection line bending magnet	
Magnet field	0.28 T
Gap height	100.0 mm
Iron length	800.0 mm
Effective length	910.0 mm
SBdl	0.25 Tm
Momentum	100 MeV/c
B r	0.33 Tm
Deflection angle	45.0 degrees
Good field region	± 75 mm
Field homogeneity in GFR	< 0.3 %
Nominal current	175 A
Max. dI/dT	100 A/s
Magnet resistance	99.6 mOhm
Max. dissipated power	3.1 kW
Inductance	63.4 mH
Max. total voltage	23.8 V
Injection line Quadrupoles	laminated, air cooled
Gradient	0.8 T/m
Aperture radius	60.0 mm
Iron length	300.0 mm
Effective length	348.0 mm
SGdl	0.29 Tm/m
Momentum	100 MeV/c
Quadrupole strength k	2.49 m-2
Focal length	1.21 m
Good field region radius	48 mm
Field quality in GFR	< 0.01 %
Nominal current	20 A
Max. dI/dT	10.0 A/s
Magnet resistance (warm)	191.7 mOhm
Max. dissipated power (dc)	76.7 W
Inductance	45.7 mH
Max. total voltage	4.3 V
Injection line H/V corrector	
Magnet field	15.0 mT
Free aperture	150.0 mm
Iron length	200.0 mm
Effective length	353.6 mm
SBdl	5.3 mTm
Momentum	100 MeV/c
B r	0.33 Tm
Deflection angle	16 mrad
Good field region (% of free aperture)	80 %
Field homogeneity in GFR	< 8 %
Electrical parameters	per plane = 2 coils in series
Nominal current	10 A
dI/dT	10 A/s
Magnet resistance	471.5 mOhm
Max. dissipated power	47.2 W
Inductance	46.0 mH
Max. total voltage	5.2 V

Table 4. Injection line magnet parameters

Resource Estimate Summary

Ring + injection line magnets	Material (kCHF)	Manpower FSU(kCHF)	Manpower FTE (MY)
Main Ring Bending Magnets (8 + 2 spares)	350		
Main Ring Combined Correctors (8 + 1)	200		
Electron Cooler Compensation Solenoids (2 + 1)	33		
Injection Line Bending Magnets (1 + 1)	80		
Injection Line Quadrupoles (3 + 1)	60		
Injection Line Correctors (2 + 1)	27		
Supports	50		
Electric and hydraulic connections	50		
Specification drawings		(64)*	
Contract follow-up		48	
Test and preparation		18	
Installation (incl. transport)		9	
Commissioning		9	
Survey	35		0.2
Engineer			0.8
Tech. engineer			1.3
Technician			0.9
Magnetic measurements		75	
Total	885	160	3.2

(*) Accounted for in design and drawings chapter

Table 5. Magnet resources

4. Power converters/cabling

The magnet data's and requirements are recapitulated in table 6. Considering the relatively low power needed, all converters are rated for DC performance. The current overall precision considered is $\pm 10^{-4}$ of the maximum current of the converter.

Circuit name	Magnet					Load	Proposed converter ratings			
	Nb of	R (mΩ)	L (mH)	In (A)	di/dt (A/s)	Voltage (V)	Current (A)	Voltage (V)	Power (kW)	Qty
Ring										
Main bending	8	71.7	26.8	182	200	154	200	200	40	1
Trim bend *	1	71.7	26.8	3	3	7	10	20	0.2	4
Multipole corr.*	1	*50*	*25*	100	100	16	100	20	2	22
Injection line										
Bending	1	99.6	63.4	175	100	33	200	50	10	1
H/V corr.*	1	472	46	10	10	9	10	20	0.2	4
Quad	1	192	45.7	20	20	13	20	20	0.4	3
e-cooler										
Solenoid	1			200	200	47	200	50	10	2
Compensator	1			200	200	47	200	50	10	2
HV	1			0.1		1000	0.1	1000	0.1	1
Corr. Coil*	1			10	10	24	10	50	0.5	10
H/V Corr.*	1			10	10	24	10	50	0.5	2
Septum										
Injection	1	6.7	0.4	991	1000	13	1000	20	20	1
Extraction	1	6.7	0.4	248	250	11	250	20	5	1

Table 6. Power converter requirements

The proposed power converter ratings and quantities are deduced from magnet parameters and DC cable voltage drop. Standardisation on existing CERN or commercial product is also taken into account. All corrector and trim (marked by*) require the 4 quadrants behaviour. The various types of converters are recapitulated in table 7 with their estimated prices. One spare converter is taken into account for type 2, 4 and 5.

Converter type	Current (A)	Voltage (V)	Power (kW)	Qty	Price (kCHF)	
					unit	total
1	200	200	40	1	70	70
2	250	50	12.5	7	20	140
3	1000	20	20	1	60	60
4	20	50	1	24	5	120
5	100	20	2	23	9	207
6	0.1	1000	0.1	1	5	5
					Total	**602**

Table 7. Power converters summary and cost

Remote control

The converter shall be controlled either by existing Mil 1553 , RS 422 or the foreseen new control system. The system shall provide the control command and status, the function generator (analogue and digital) and the acquisition over the full machine cycle.

The remote control costs are not taken into account in our estimate.

Installation

The power converter installation is foreseen in building 193; in place of the AD return loop power converters which have been dismantled in 2005. The converter type 1 and 3 shall occupy each a space of 2 racks. The rest of the converter shall be installed in 12 individual racks. This results in a cost of 15 kCHF.

AC cabling

The ac supply of the converter system shall be feed from the existing distribution panel whose feeders have been free from the AD return Loop. The need is 2 line of 16 A per racks, over a distance of ~ 20 m.

The estimated price per ac cable is 200 CHF, on which 50 CHF is to be added for the connections. The estimated ac cabling cost is then 250 CHF per 16 A ac feed. Making a total cost for the ac cabling of 6 kCHF for the 12 racks. Two line of 125 A have to be added for converter type 1 and 3 which will bring the total for the ac cabling to 8 kCHF.

TS/EL is responsible for this item, and shall be submitted for approval.

DC cabling

The estimated cable length between the equipment building 193 and the ELENA ring is estimated at 120 m. The cost of dc cabling is recapitulated in table 8. It should be noted that the cabling cost for the converters of type 5 (100 A) is almost a factor four higher then for type 3 (20A). Considering the cable cost saving, we would strongly recommend designing corrector magnets with lower current and higher voltage then the contrary.

Converter type	Current (A)	Qty	Cable type	cost/m	ends	total cost (kCHF)
1	200	1	2 x 150	40	40	4.84
2	250	6	2 x 150	40	40	29.04
3	1000	1	6 x 240	180	360	21.96
4	20	23	2 x 10	7	30	20.01
5	100	22	2 x 70	30	30	79.86
6	0.1	1	2 x 10	7	30	0.87
Total DC cabling						156.58

Table 8. dc cabling cost

Interlocks

TS/EL responsible for this item, propose 60 kCHF for this item, which represent ~1 kCHF per magnet. A complement of 5 kCHF for cable trays extension shall be taken into account. Alternative solution using PLC will be considered at a later stage.

Resource Estimate Summary

The estimated costs and resources for the project are:

Power converters, ring + inj.line	Material (kCHF)	Manpower FTE (MY)
Power converter including installation	617	1
Cabling ac dc and magnet interlocks	240	0.5
Total	857	1.5

Table 9. Power converter resources

The power converter group is in charge of the power converter and their installation in the building.

All cabling ac, dc, interlocks is the responsibility of TS/EL. The proposed solutions and estimates including 10 kCHF for unforeseen have been approved by TS/EL

Connections to the remote control system are not included.

5. Injection/ejection septa

Layout

This resource estimate is based on the layout sketched in Fig. 7. Space shall be reserved for Ø50 mm incoming and extracted beam chambers. Space shall also be reserved for a Ø100 mm orbiting beam chamber. The physical injected beam size assumed was Ø28 mm, while for the extracted beam Ø26 mm was used. The incoming beam shall be at 21° with respect to the straight section, while the extracted beam shall be at 30° with respect to the straight section.

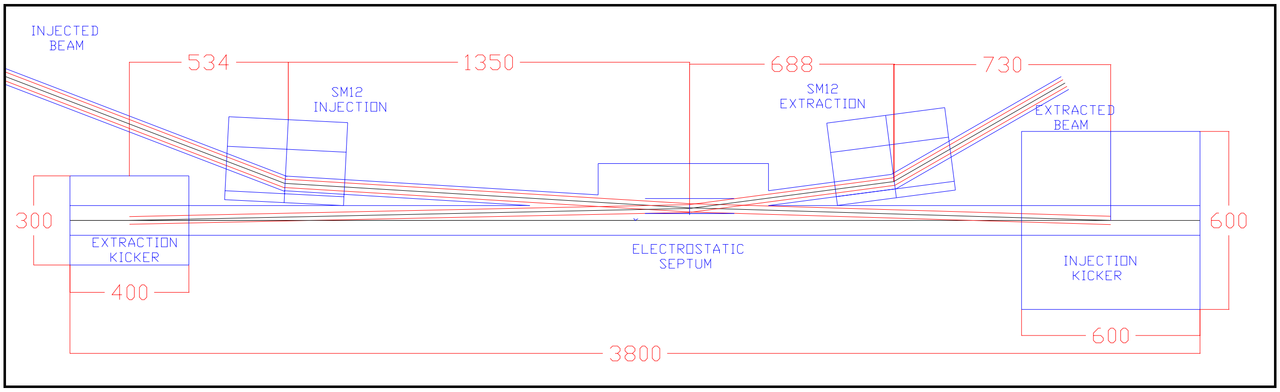


Fig.7. **Layout of the injection and extraction area (all dimensions indicated are physical lengths)**

The beam is first deflected by a magnetic DC septum recovered from LEAR, previously called SM12. Subsequently the beam is further deflected by an electrostatic septum before entering the injection kicker. The electrostatic septum shall be purpose designed and built for this specific application. The extracted beam is first deflected by the extraction kicker to enter the gap of the electrostatic septum. The voltage applied to this septum shall be adjustable and dependant on the extraction energy of the beam. Subsequently the beam passes through a second magnetic DC septum identical to the magnetic injection septum (previously, the SM12 spare septum for LEAR). Table 10 summarises the principal parameters for the magnetic septa, while Table 11 summarises the parameters for the electrostatic septa, both for injection and extraction.

SEPTA

Magnetic Septa

The magnets and coils already exist at CERN and can be installed in the injection and extraction lines to and from ELENA. No spare coil is foreseen to be built, taking into consideration the fact that the magnets will operate at less than half of their design current. New mechanical supports need to be designed and constructed for the magnets and the vacuum chambers. Removal of the magnets is foreseen to allow the vacuum chambers to be baked out. Purpose built electrical bus bars and new demineralised water manifolds need to be designed, manufactured and installed. A dedicated interlock system (PLC based) will also be required. To note that the supply of the power converters and the design and supply of the vacuum chambers is not considered to be under the responsibility of the BT group.

Magnetic septa	Injection septum	Extraction septum	
Deflection angle	303	392	mrad
Beam momentum	100	13.7 (19.4)	MeV/c
Beam energy	5.3	0.100 (0.200)	MeV
Integrated magnetic field (∫B.dl)	0.101	0.018 (0.025)	T.m
Gap field	0.337	0.060 (0.084)	T
Gap height	74		mm
Gap width between conductors	135		mm
Magnet length (physical)	400		mm
Magnetic equivalent length	300		mm
Septum conductor thickness	22.8		mm
Number of conductor turns	20		
Current (DC.)	991	176 (248)	A
Magnet inductance	400		μH
Magnet resistance	6.7		mΩ
Demineralised cooling water requirement			l/min.

Table 10. **Technical specifications of the magnetic septa (between brackets the alternative extraction energy values)**

Electrostatic Septum

The electrostatic septum shall form an integral part of the ELENA ring itself. The purpose built electrostatic septum will have to be designed from scratch. It will use a titanium plate (1 mm thickness) as septum, since the device will be operated with a positive voltage on the electrode because of the antiprotons. No remote displacement system will be foreseen for the septum or for the electrode, thus minimising cost and complexity. The septum shall be designed and constructed to cope with the extremely severe vacuum requirements of ELENA. The vacuum vessel will be equipped with ion pumps, titanium sublimators and NEG coated surfaces. It will be bakeable at 300ºC to obtain a vacuum of 10^{-12} mbar. The device shall incorporate a dedicated mechanical support. No spare septum is foreseen to be built, since the time needed for a repair is of little influence on the down time of the machine, which will be dominated by the bake-out time in the case of an intervention. Only spare parts for long-lead items such as certain HV components will be manufactured. The power supply shall be procured from industry, and an interface shall be provided (PLC based) to take into account the septa interlocks. The device shall be capable of changing its operational mode from injection to extraction settings within 3 seconds.

Electrostatic septa	Injection settings	Extraction settings	
Beam momentum	100	13.7 (19.4)	MeV/c
Beam energy	5.3	0.100 (0.200)	MeV
Deflection provided by septum	30		mrad
Required electric field	1.272	0.088 (0.176)	MV/m
Gap between electrodes	50		mm
Nominal voltage	63.6	4.4 (8.8)	kV
Septum thickness (titanium)	1		mm
Septum length	0.300		m
Anode length (stainless steel)	0.250		m
Septum position w.r.t. orbiting beam axis	24		mm
Tank length	0.500		m

Table 11. **Technical specifications of the electrostatic septum (between brackets the alternative extraction energy values)**

Resource Estimate

The budget estimate is given in 2006 prices. For both magnetic septa the installation cost amounts to 50 kCHF (excluding the magnets which are already available at CERN) and 1.0 m.y. of manpower (see table 12). For the electrostatic septum the cost estimate is approximately 170 kCHF and 1.9 m.y. of manpower, including the control electronics. Items like design office and industrial support are included under the material cost.

Magnetic septa		
Mechanical supports	12	kCHF
Water battery	12	kCHF
Interlock system, PLC's	15	kCHF
Bus bar	5	kCHF
Cabling, installation	6	kCHF
Total for both magnetic septa	**50**	**kCHF**
Cat 2	0.1	m.y.
Cat 3	0.3 + 0.3	m.y.
Cat 4	0.3	m.y.
Total manpower	**1.0**	**m.y.**

Table 12. **Resource estimate for the Magnetic Septa (magnets not included)**

Electrostatic septum		
Mechanical support	5	kCHF
Vacuum vessel	25	kCHF
Vacuum components (VPI, Ti sublimator, NEG, heating jackets, gauges)	22	kCHF
HV components (feedthrough, HV deflectors, septum, anode, incl. Spares)	35	kCHF
Power supply	12	kCHF
Interlock system, PLC's	15	kCHF
Cabling	10	kCHF
Design office	46	kCHF
Total for electrostatic septum	**170**	kCHF
Cat 2	0.7	m.y.
Cat 3	0.4+0.4	m.y.
Cat 4	0.4	m.y.
Total manpower	**1.9**	**m.y.**

Table 13. **Resource estimate for the Electrostatic Septum**

Resource Estimate Summary

Injection/ejection septa	Material (kCHF)	Manpower FSU(kCHF)	Manpower FTE (MY)
2 magnetic septa	50*		1.0
Electrostatic septum	170		1.9
Total	220		2.9

(*) Foresees the use of existing magnets

Table 14. **Injection/ejection septa resources**

6. Injection/ejection Kickers

Proposed displacement of AD Kicker modules for ELENA implementation.

A part of the kicker platform which contains equipment for 4 kicker modules has to be relocated in order to make place for the ELENA ring. The smaller of the two blocks represent the PFN cable drums, whilst the larger represents the steel platform holding the HV switches and associated equipment. Rack space for the control electronics can be found by reconfiguring and re-cabling of adjacent kicker module racks.

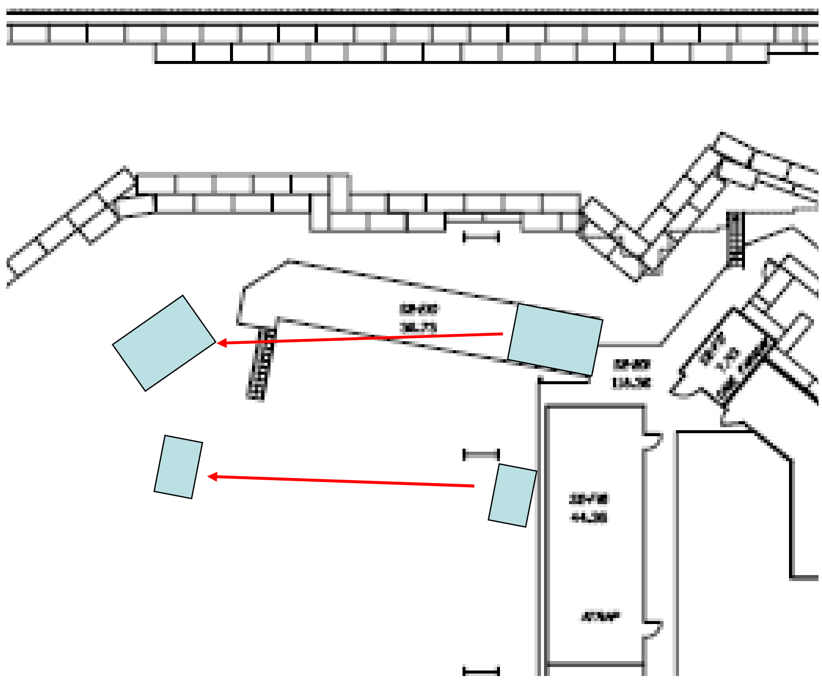


Fig.8. Kicker PFN platform relocation

Both kicker modules have to be fully bakeable. Basic parameters can be found in table 15.

Injection kicker	
Required angle @5.3 MeV, mrad	30
Magnetic length, mm	505
Magnetic strength, G•m	100
Max. rise/Fall time, ns	300
Flat top, ns	400
Good field region, h/v mm (=gap height/width)	50/50
Vacuum tube connectors	Flange for ¢ =100mm
Ejection kicker	
Required angle @200 keV, mrad	30
Magnetic length, mm	275
Magnetic strength, G•m	20
Max. rise/Fall time, ns	1000
Flat top, ns	400
Good field region, h/v mm (=gap height/width)	50/50
Vacuum tube connectors	Flange for ¢ =100mm

Table 15. **Kicker specifications**

Kicker system costs					
	Magnet & vacuum tanks	HV power supplies	Electronics	Fluids systems	Cost (kCHF)
Injection kicker	150	20*	150	30	330
Ejection kicker	85	150	100	15	350
Displacement of AD equipment	150				

(*) Foresees the re-use of spare AD equipment

Table 16. **Kicker costs**

Resource Estimate Summary

Injection/ejection kickers	Material (kCHF)	Manpower FSU(kCHF)	Manpower FTE (MY)
Total	830		4.8

Table 17. **Injection/ejection kicker resources**

7. Electron cooler

Electron Cooling for ELENA

Electron cooling will be essential in ELENA in order to obtain the small emittance antiproton beams needed for extraction to the trap experiments. Given the space available in the ring, the cooling section will occupy one of the 5m long straight sections of the machine. The cooler itself will take up almost half the available space and the rest of the section will accommodate the machine quadrupoles and the compensation solenoids of the cooler.

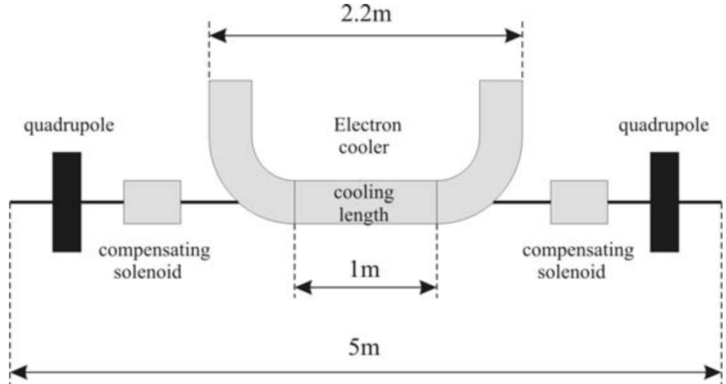


Fig.9. **Electron cooler section**

Cooling will be needed at two momenta during the ELENA deceleration cycle. At the intermediate momentum of 35 MeV/c the antiproton beam will need to be cooled in order to guarantee that it can be decelerated further to 14 MeV/c without any excessive blowup of the beam dimensions which could lead to beam loss. At 14 MeV/c the cooling will ensure that the phase-space characteristics of the extracted antiproton beam fit the requirements of the experiments. For fast and efficient cooling special attention must be paid to the design of the electron gun and the quality of the longitudinal magnetic field guiding the electrons form the gun to the collector. The main characteristics of the proposed device are summarized in table 17.

The electron gun must produce a cold ($T_\perp < 0.1$ eV, $T_\parallel < 1$meV) and relatively intense electron beam ($n_e \approx 3\text{x}10^{12}$ cm^{-3}). The use of a photocathode cannot be considered as it is complicated to operate and has a short lifetime. Instead a conventional thermionic cathode will be used and the electrodes will be designed in such a way to minimise the transverse temperature after acceleration to the desired energy. The gun is immersed in a longitudinal field of 700 G which is adiabatically reduced to maximum field of 200 G in the transition between the gun solenoid and the toroid. In this manner the transverse temperature can be reduced further through adiabatic beam expansion. The lower field in the toroids and cooling section is also necessary to facilitate the compensation of the perturbations (closed orbit distortion and coupling) induced by the electron cooler. After the gun, the electrons are bent in a 90º toroid where they merge with the circulating antiprotons over a distance of 1m. At the exit of this cooling section, the electrons are bent away from the antiprotons by a second 90º toroid. The complete magnetic guiding system will consist of a series of small solenoid "pancakes" which can be individually adjusted. In this manner the transverse components of the longitudinal field are kept small ($B_\perp/B_\parallel < 10^{-4}$) ensuring a minimal perturbation to the electron beam transverse temperature. To improve the electron beam collection efficiency, the use of electrostatic bending plates in the toroids can also be envisaged. Their usefulness has been demonstrated on recent coolers and in a machine like ELENA, where the vacuum must be kept as low a possible, they will help to ensure that electron losses are kept to a minimum. The vacuum system will be the same as was used for the LEIR cooler, namely; NEG cartridges at the gun and collector where the gas load is the highest, NEG strips in the toroid chambers, and NEG coating of the vacuum chamber as well as ion pumps in the cooling section.

Momentum (MeV/c)	35	14
□	0.037	0.015
Electron beam energy (eV)	355	57
Electron current (mA)	15	2
Electron beam density (cm^{-3})	4.3×10^{12}	1.4×10^{12}
Bgun (G)	600	
Bcooling section (G)	150	
Expansion factor	4	
Cathode radius (mm)	12.7	
Electron beam radius (mm)	25.4	

Table 18. **Main characteristics of the ELENA cooler.**

The estimated cost of such a cooler is about 1.35MCHF (not including power supplies) over a 3 year period. The breakdown of the required resources over this period is summarised in the table below. 50 kCHF is estimated for controls equipment: VME crate + modules

	Year 1	Year 2	Year 3
Budget	200 kCHF	800 kCHF	350 kCHF
Manpower	0.5 Eng., 0.5 Tech.	1 Eng., 1 Tech.	1 Eng., 1 Tech., 1 Mech.

Table 19. **Breakdown of resources required for the ELENA cooler design, construction and commissioning.**

The cost for software development for cooler controls is not included in this estimate.

Resource Estimate Summary

Electron cooler	Material (kCHF)	Manpower FTE (MY)
Total	1350	6.5

Table 20. **Electron cooler resources**

8. Vacuum system

The ELENA ring will be fully bakeable (300 C) with NEG coated chambers. Ring average pressure should be around 1*E-12. Permanent bake-out equipment is installed in the magnets. Mobile mechanical pumping groups and mobile diagnostics (RGA) will be used.

Etude, prototypes, suivi	**Nombre**	**Prix unité (CHF)**	**Prix (kCHF)**
Bureau de dessin (heures) *	1’000	51	(51*)
Prototypes			80
Déplacements, visites usines	10	5’000	50
		Total étude, prototypes, suivi:	**130**

Arc (4 cellules de 2 dipoles + 1 multipole)	**Nombre**	**Prix unité (CHF)**	**Prix (kCHF)**
Chambres dipole (“vacuum fired & NEG coated”)	8	5000	40
Chambres quad (“vacuum fired & NEG coated”)	8	3’500	28
Compensateurs (avec contacts RF)	16	4’500	72
Chambres de pompage	4	5’000	20
Pompes ioniques avec alimentation	4	8’000	32
Jauges Pirani avec alimentation	4	1’000	4
Jauges Penning avec alimentation	4	1’500	6
Vannes de secteur	8	20’000	160
Vannes de prévidage	4	2’500	10
Câblage (m)	500	10	5
		Total arc:	**377**

Sections droites	**Nombre**	**Prix unité (CHF)**	**Prix (kCHF)**
Chambres (“vacuum fired & NEG coated”)	8	3’000	24
Compensateurs (avec contacts RF)	16	4’500	72
Chambres de pompage	6	5’000	30
Transitions	8	2’500	20
Pompes ioniques avec alimentation	8	8’000	64
Jauges Pirani avec alimentation	4	1’000	4
Jauges Penning avec alimentation	4	1’500	6
Vannes de secteur	0	2’000	0
Vannes de prévidage	4	2’500	10
Câblage (m)	300	10	3
Supports	30	500	15
		Total sections droites:	**248**

Etuvage	**Nombre**	**Prix unité (CHF)**	**Prix (kCHF)**
Equipement de chauffage et thermocouple	50	1’500	75
Racks de réglage	4	15’000	60
Consomables			5
		Total étuvage:	**140**

Pompage et diagnostic mobile	**Nombre**	**Prix unité (CHF)**	**Prix (kCHF)**
Groupes de pompage	2	20’000	40
Boîtes magiques	2	50’000	100
Détecteurs de fuites	1	20’000	20
		Total pompage et diagnostic mobile:	**160**

Système de contrôle et interlocks	**Nombre**	**Prix unité (CHF)**	**Prix (kCHF)**
PLC (secteur)	2	6’000	12
PLC (groupes, boîtes magiques)	4	4’000	16
Chassis interlocks	1	5’000	5
Chassis vannes	8	4’000	32
Entrée / sorties déportées	4	3’000	12
Câblage (m)	100	30	3
Racks	4	2’500	10
Software de supervision (collaboration)	1	30’000	30
		Total système de contrôle et interlocks:	**120**

Installation	**Nombre**	**Prix unité (CHF)**	**Prix (kCHF)**
Mécanique (h)	200	60	12
Détection, réparation (h)	40	80	3
Contrôles	40	60	2
Suivi qualité	80	120	10
		Total installation:	**27**
		Total général:	***1’202***

(*) Accounted for in the design and drawings chapter

Table 21. Vacuum equipment

Resource Estimate Summary

Vacuum	Material (kCHF)	Manpower FSU (kCHF)	Manpower FTE (MY)
Total	1175	27	5.0

Table 22. Vacuum resources

9. RF system + Schottky diagnostics

RF System

RF Operations and Components

The ELENA RF system serves to capture the injected antiproton beam from the AD through bucket to bucket transfer, decelerate the beam from the injection momentum of 100 MeV/c (T = 5.3 MeV) to an intermediate momentum of typically 35 MeV/c (T= 653 keV) and adiabatically de-bunch the beam for electron cooling.

This if followed by adiabatic rebunching of the beam for further deceleration to the extraction momentum of 13.7 MeV/c (T = 100 keV), another de-bunching, cooling and re-bunching for extraction to the experiments.

The RF system consists of an RF cavity, an ultra low noise longitudinal pick-up system, and a low level RF system.

As in the AD, the ultra low noise longitudinal pick-up is in also used for intensity measurements by RF current measurements when the beam is bunched as well as longitudinal Schottky scans (momentum spread and intensity) when the beam is debunched. The signal processing for these measurements are an integral part of the low level RF system.

Typical Beam and Machine Parameters and RF Voltage Requirements

The circumference of Elena is C_{ELENA} = 26.06 m = C_{AD} / 7 such that straightforward synchronized bucket to bucket transfer can take place at every turn from AD to ELENA.

The required RF frequency range for h = 1 operation is therefore a ratio of about 7 from **1.22 MHz to 168 kHz**.

The ELENA lattice is assumed to have a momentum compaction factor $\alpha = 1/\gamma_{tr}^2 = 0.65$ or γ_{tr} = 1.24.

With a well adjusted electron cooling in the AD and using electron cooling during the iso-adiabatic capture at 100 MeV/c, the AD is capable of delivering a longitudinal emittance of **1.3 meVs** [95%].

Assuming that the electron cooling is capable to cool the de-bunched beam to a relative momentum spread of $\Delta p/p = 10^{-4}$ both at 35 and 13.7 MeV/c, the longitudinal emittance gets further reduced to **0.3 meVs** at 35 MeV/c and **0.1 meVs** at the extraction momentum of 13.7 MeV/c.

At injection the required voltage to match the ELENA bucket to the AD bucket using 500 V_p in the AD is 4 V_p. This corresponds to a bunch length of 230 ns for E_{lon} = 1.3 meVs. Much larger longitudinal emittances can easily be transferred if needed by using a higher RF voltage in ELENA and bunch rotation in the AD.

To obtain an extracted bunch length of about 300 ns with E_{lon} = 0.1 meVs an RF voltage of 11 V_p is required. The corresponding $\Delta p/p = 1.4\ 10^{-3}$ [4σ, 95%].

The bucket area with V_{RF} = 11 V_p produces a stationary bucket area of about 15 meVs without much variation with energy. Assuming a deceleration or ramp time of 5 seconds, an energy loss of 1.5 Volts per turn is required, and the moving bucket area will be reduced to about 11.5 meVs, which seems adequate.

The minimum RF voltage required is the initial RF voltage required for iso-adiabatic capture of the cooled (0.1 meVs) beam prior to extraction. A full bucket is obtained with only V_{RF} = 0.7 mV, and even with such an initial capture voltage significant longitudinal blow-up will take place. With and adiabaticity coefficient of 0.3, the required duration of the capture is 1.4 seconds. Like in the AD, better extracted longitudinal emittances may be obtained by keeping the electron cooling on during a part of the capture.

A **controlled voltage range of 0.7 mV to 11 V** is therefore suggested. This corresponds to a dynamic range of 16000 or 84 dB which is larger than the 70 dB currently achieved in the AD with analog logarithmic detectors and. However, by using digital receivers and digital modulators with switch-able DAC range as used in the LEIR RF system this can hopefully be achieved.

The challenge in the ELENA RF system therefore the large dynamic voltage range required.

Longitudinal Pick-up

A low noise phase pick-up is required for the low level RF system phase loop, and additionally with adequate bandwidth to measure the bunch length at the lowest revolution frequency (low frequency cut-off ~20 kHz, base line droop) and at the shortest bunch length encountered (high frequency cut-off ~20 MHz).

Additionally, if the noise level is low enough, the same pick-up can be used to measure longitudinal Schottky scans.

A pick-up composed of two doubly shielded ferrite cavities with integral ultra low noise JFET head amplifiers with low noise feedback like those built for the AD is proposed [2]. It consist of a high frequency unit like DR.USY4104 (high frequency 4L2 ferrites, $\mu = 200$, bandwidth 0.3 – 20 MHz, noise current) and a low frequency unit like DR.USY4105 (low frequency 4A15 ferrites, $\mu = 1200$, bandwidth 0.02 – 3 MHz). The two signals are summed in an amplifier with appropriate equalizers to ensure a combined bandwidth of 0.02 – 20 MHz. The crossover frequency is 1 MHz as the low frequency unit has the lowest noise below that frequency (typically 2.5 pA/sqrt(Hz)) while the high frequency unit has the lowest noise above that frequency (typically 1.5 pA/sqrt(Hz)).

If space is a problem (each unit is 54 cm flange to flange), shorter units (with higher noise levels) or a combined unit with both cavities within the same outer shielding could be developed.

Surplus 4L2 rings are available from the Booster, and do not need to be purchased.

The Schottky currents per particle and the number of particles are comparable to the AD numbers as the range of revolution frequencies are about the same. The worst case longitudinal Schottky signal to noise ratios are however slightly better than the AD as there is nowhere in the ELENA cycle where the width of the Schottky bands are as wide as the initial distribution in the AD after de-bunching at 100 MeV/c.

RF Cavity and Power Amplifier

The RF cavity could be built with either finemet or ferrite cores. Due to the low voltage requirements, there is no need to tune the cavity, and adequate broad band response is obtained by loading the cavity. With ten 4A15 ferrite rings (ferrite length 30 cm, μ = 1200) as used in the low frequency pick-up cavity, sufficient inductance (40 μH) is obtained to drive the resistively loaded cavity to the required voltage with a modest power amplifier of only 20W. A 4:1 step down transformer (like DR.USY4105) transform the 50 ohm load impedance to 3.125 ohms at the gap. To obtain 11 Volts peak at the gap, 44 Volts peak must be applied to the input of the 4:1 transformer integrated in the cavity.

A cheaper and shorter RF cavity may possibly be built using finemet cores.

Low Level RF System, Intensity measurements

The low level RF system is based on the software and digital building blocks developed for LEIR.

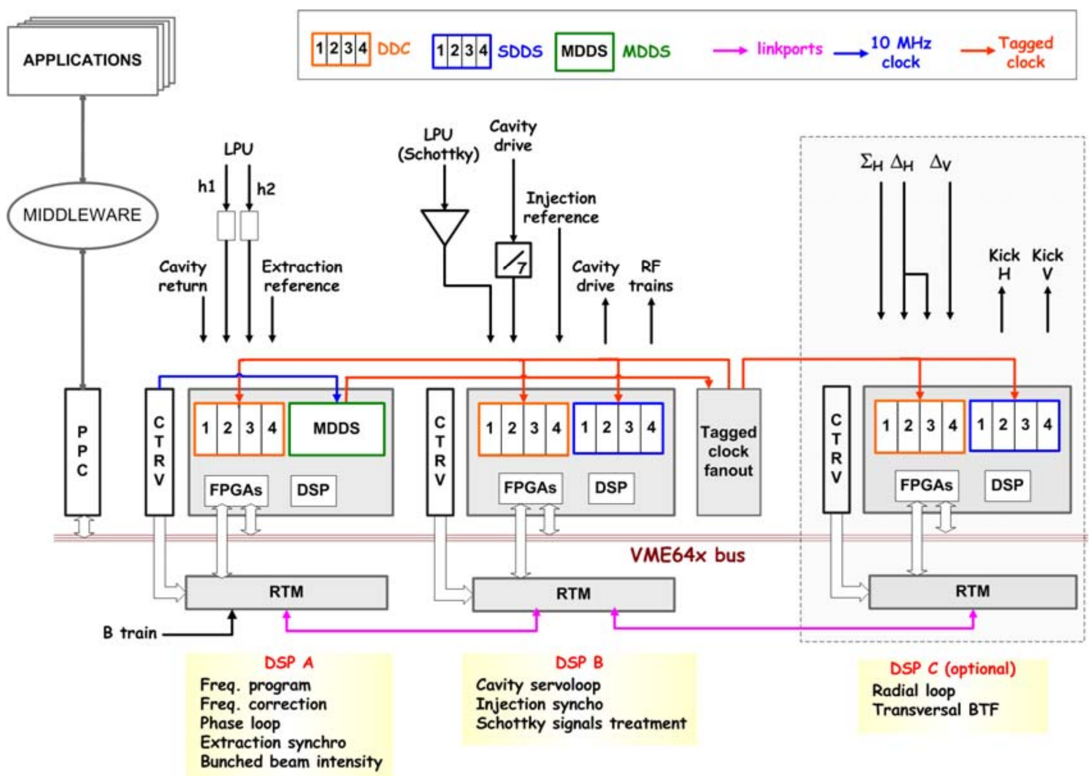


Fig.10. **Block diagram of the Elena RF and intensity diagnostics system.**

As in the AD, the beam currents are much too low to enable intensity measurements by a DC beam current transformer. RF current measurements at two harmonics (h = 1 and 2) are used for intensity measurement when the beam is bunched, and longitudinal Schottky power is used when the beam is de-bunched. The implementation of these functions (similar to AD [3]) in the digital low level RF system architecture is straightforward as the beam phase signal is already received in a DDC (Digital Down Converter) for use in the beam phase loop.

The basic low level RF system including the intensity and momentum distribution diagnostics can be implemented on two VME DSP mother boards, see fig. 1.

The Master DDS (located on DSP A mother board) operates on a suitable high harmonic of the revolution frequency, and drives all NCO's (Numerically Controlled Oscillators) in the Slave DDS's and DDC's with controlled relative phases.

DSP A receives a B-train derived from a coil in one of the bending magnets, and generates the basic frequency program. A software function generator generates a frequency correction function to correct for errors in the measured B-train. The DSP A also looks after the beam phase loop, the extraction synchro loop and the bunched beam intensity measurement based on the amplitude of first and second harmonic of the beam RF current.

The RF system requires a B-train system (preferably measured and synthetic as in the AD) to generate the frequency program, but this sub-system is not included in the RF system cost estimates below.

The second board DSP B looks after the digital cavity voltage servo loop, the injection synchro loop where the 7^{th} sub-harmonic of the Elena RF signal is locked to the AD RF (= injection reference) prior to bucket to bucket transfer. The longitudinal Schottky treatment when the beam is debunched is also treated in DSP B: a high gain version of the longitudinal pick-up is connected to a DDC clocked at a fixed 40 MHz rate and tuned to an appropriate revolution harmonic (optimized for signal to noise ratio and best Schottky statistics).

If the tune measurement system using transverse BTF (Beam Transfer Function) as in the AD is required [4], a third DSP C board is needed. The generation of the digital M-shaped coloured noise excitation signal is straightforward with the SDDS daughter card using an appropriately filtered baseband noise excitation file. Besides transverse BTF, this board could also implement a radial loop (using a single pick-up) as has been developed for the LEIR.

Estimate of Elena RF and Longit. Schottky diagnostics system

Item	Description	Material [kCHF]	Personell [FTE]
Low noise pick-ups for bunch lenghts, RF intensity, beam phase loop and long. Schottky			
PU LF (4A15 ferr.)	Low frequency pick-up (0.02 - 5 MHz	60	0.2
PU HF (4L2 ferr.) *)	High frequency pick-up (0.3 - 25MHz)	30	0.2
PU electr.	Electronics PU's (head+sum)	10	0.2
Low voltage broadband cavity and amplifier (1 mVp - 10Vp, 0.17 - 1.22 MHz)			
Cavity LF	Loaded ferrite/finemet cavity	60	0.2
Power Amplifier	~20 W if 4A15 ferrites used	5	
Digital low level RF, incl. bunch beam intensity and Schottky diagnostics			
VME crate	VME 64x with CPU	9.0	
CPU	Power PC	7.0	
2 DSP mother boards	2 x (RTM+DSP)	4.8	
Timing	2 x CTRV VME modules	1.4	
Master DDS	1 x MDDS	1.2	
Clock Fan-Out	1 x VME Clock Fan-out	1.0	
4 ch. Receiver	2 x 4 ch DDC daughter cards	4.0	
4 ch. Modulator	1 x 4 ch. SDDS daughter card	2.0	
HW tests and commissioning			0.2
Transverse BTF and Radial loop			
2 DSP mother boards	1 x (RTM+DSP)	2.4	
4 ch. Receiver	1 x 4 ch DDC daughter cards	2.0	
4 ch. Modulator	1 x 4 ch. SDDS daughter card	2.0	
Timing	2 x CTRV VME modules	1.4	
HW tests and commissioning			0.1
Lab equipment and spares			
Lab equipment	VME crate, Power PC, scope etc.	30	
Spare modules	Approx. 50% of system	20	
Digital LLRF and Longitudinal Diagnostic Software			
Global system design	All 3 layers for the 3 main items below		0.2
DSP, RTT, Appl.	Digital LLRF Software integration (DSP, RTT,App)		0.4
DSP, RTT, Appl.	Longit. Bunched beam intensity and Schottky		0.6
DSP, RTT, Appl.	Transverse BTF and Radial loop		0.5
Global system integration, commissioning with beam and setup			0.2
Diagnostic specific application (as for AD), provided by OP?			0.3
Cables, installation (FSU)		50.0	0.1 (FSU)
Total		303.2	3.3

*) ferrites for HF PU cavity recuperated from PSB stock

Table 23. **RF and Schottky system components**

Resource Estimate Summary

RF+Schottky	Material (kCHF)	Manpower FSU (kCHF)	Manpower FTE (MY)
Total	303	10	3.3

Table 24. **RF and Schottky diagnostics resources**

10. B-train systems

Both synthetic and measured B-trains will be used, with systems based on what is presently used in the AD and other machines in the PS-complex. Modernized electronics for the measured B-train is under study and will replace existing systems CERN-wide.

Synthetic B-train:

- VME-crate: 7 kCHF
- CPU: 6 kCHF
- CTRV+BTG cards: 2 kCHF
- Development (modeling/sw): 4 man-months

Measured B-train:

- Electronics: 15 kCHF
  (VME rack, data conditioning and acquisition, interface to machine control)
- NMR: 30 kCHF
  (estimated for the upcoming Metrolab PT2026, which should be fast enough for ELENA purposes, with one probe)
- Flux coil: 20 kCHF
  (1.5 m long coil, 45° bend, 1 unit + 1 spare)
- Installation and testing: 4 man-months

Resource Estimate Summary

B-trains	Material (kCHF)	Manpower FSU (kCHF)	Manpower FTE (MY)
Total	80		0.7

Table 25. **B-train resources**

11. Diagnostics

ELENA ring BPM Pickups

The proposed design is based on a stainless steel body containing 2 diagonal cut electrodes. Two such elements can be inserted in to a vacuum tank 140mm diameter and 400mm long or shorter if needed, in order to have a position measurement in both planes. In contrary to the ring PU no sigma electrode will be installed, but the sigma signal will be generated in the head amplifier. An existing head amplifier design made for Aarhus University 5 years ago can be used.

The Delta and Sigma signals will be acquired by a network analyzer as in the AD in order to obtain a good signal to noise ratio (BW~ 100Hz). Measurement time per PU ~30ms.

The theoretical resolution at 1*107 charges in a 3.4S bunch (15m) with beta = 0.0146 and a bunching factor of ~2 is 0.1mm (S/N=20). This resolution is calculated using theoretical white noise only, but as we know from the AD interference can be much higher. A similar performance as for the AD orbit should be possible.

	Units	**CHF/Unit**	**CHF**
Prototype	1	10k	10k
Manufacturing of Pus (H+V)	7	10k	70k
Cables	7	5k	35k
Head amplifier design	0	0	0
Manufacturing of HA	10	1k	10k
Other electronics design	1	6k	6k
Manufacturing other electronics	7	1k	7k
VME crate + VME module	1	17k	17k
Network analyzer	1	50k	50k
Other	1	20k	20k
TOTAL			**225 kCHF**

Table 26. **Estimated costs**

	Man months	**Comments**
PU design	6 (Eng)	In coll. with mech. designer
Prototype test	1 (Eng)	On test bench
Manufacturing of Pus (H+V)	1 (Tech)	Follow up of AP work
Tests of PUs	2 (Tech)	On test bench
Head amplifier design	0	Existing Aarhus amp.
Manufacturing and tests of HA	1 (Tech)	
Other electronics design	1 (Eng)	Control mod, signal distr.
Manufacturing other electronics	1 (Tech)	
Software	3 (Eng)	Copy from AD but on FESA
Installation	1 (Tech)	
Tests and commisioning	1 (Eng)	
Other	1 (Eng)	
TOTAL	**6 Tech.;14 Eng.**	

Table 27. **Estimated manpower**

ELENA emittance measurement using scrapers

This is a very rough cost estimate made on the assumption that the existing system for the AD can be copied, and that the drawings can be found. The system consist of 4 motorized scrapers, 2 scintillators with photo multipliers and high voltage supplies. Outside the ring a discriminator and summing modules (NIM) and a counter module (VME scaler) are needed.

	Units	**CHF/Unit**	**CHF**
Scraper mechanics incl. motors	4	10k	40k
Vacuum Tank	1	6k	6k
Motor controller	4	3k	12k
Cables	6	1k	6k
Scintillators	2	2k	4k
Photo multipliers	2	3k	6k
Nim modules	3	4k	12k
NIM crate	1	5k	5k
VME module (scaler)	1	4k	4k
VME crate	1	15k	15k
TOTAL			**110 kCHF**

Table 28. Estimated cost

	Man months
Design scintillators and support	1 (Tech)
Software	3 (Eng)
Manufacturing and installation	1 (Tech)
TOTAL	**2 Tech.;3 Eng.**

Table 29. Estimated manpower

Electron Cooling Related Diagnostics

In order to observe and optimise the cooling of low energy antiprotons in ELENA non-destructive diagnostics need to be developed. The measurement of the longitudinal cooling can only be done using Schottky diagnostics. A longitudinal Schottky pick-up will not only give the measurement of the momentum spread of the beam but also the beam intensity. In the transverse planes ionisation profile monitors (IPM) are the ideal instruments for measuring the evolution of the beam size throughout the deceleration cycle. However in a machine like ELENA where the vacuum will be in the 10^{-12} torr range and the intensity of the circulating is low, a gas injection system, similar to what is used on the AD, must also be installed. It is clear that the use of an IPM in ELENA would be limited to the machine commissioning/startup and for machine development. A horizontal monitor could be installed in one of the horizontal bending magnets and the vertical monitor would have its tank in one of the machine straight sections. The resolution of these detectors would be around 1mm.

If H^- injection is to be used on ELENA, a most useful detector would be a recombination detector placed at the exit of the bending magnet downstream from the electron cooler. This detector measures the radiative recombination rate of the electrons with the circulating proton beam. Coupled to a luminescent screen one observes directly on a monitor the transverse cooling of the proton beam.

Cost estimate:

2 IMPs (H & V), including HT power supplies, front-end electronics and DAQ system: 150 kCHF.

Recombination detector, including HT power supplies, CCD camera and DAQ system: 70 kCHF.

VME crate + modules: 30 kCHF

Tune measurement

See RF/Schottky for transverse BTF DSP-system. A dedicated kicker of a similar design to the one used in LEIR will be required. Cost including stripline structure, vacuum feedthroughs, electronics and amplifiers is estimated at 35 kCHF and 0.3 MY.

Intensity measurement

See RF/Schottky

Resource Estimate Summary

Diagnostics	Material (kCHF)	Manpower FSU (kCHF)	Manpower FTE (MY)
Total	620	85	2.4

Table 30. **Diagnostics resources**

12. Controls

Controls	Material(kCHF)	Manpower CERN FTE (MY)
OASIS (150MHz chassi + 500MHz chassi)	192	
Communication network	80	
Timing system	40	
General cabling	80	
Controls infrastructure in local control room	0	
Timing DSCs (2DSCs + 30 CO modules)	60	
Power suplies interface (2 DSCs + CO modules, does not include power controls budget prevision)	60	
Power controls FGC3 (35 supplies)	70	
Power controls PLC (100 HVsupplies)	100	
HW installation + SW development/adaptation		0.35
Cycle generation SW (LSA)		0.35
Total	682	0.70

Table 31. Controls resources

13. H- source

Discussions are underway to determine whether part of the ELENA setting-up can be done using a local H- source. The objective is to be able to do part of the commissioning independent of the CERN accelerator complex and it's run schedule. A 100 keV H- source can temporarily be installed in the new section of the AD to ELENA transfer line for commissioning and initial setting up of the electron cooler at 100keV and of the ejection lines.

Resource Estimate Summary

H- source	Material (kCHF)	Manpower (MY)
H- source	100	
Power supply	250	
Div.	50	
Total	400	0.5

Table 32. **H- resources**

14. Experimental area beam lines + instrumentation

Beam transport

Transport of 100 keV beams will not be an easy task, especially considering the operational difficulties experienced in keeping beam trajectories stable with today's AD setup where ejection beam energy is 5.3MeV (a factor 7 higher momentum). To gain better understanding of the problem, a study of the environmental magnetic fields in the area will have to be done.

Many solutions exist, including re-arrangement of the experimental areas in order to avoid passing through areas where fringe fields from experimental equipment are present. The final solution will also depend on the different experiments possible needs for both 5.3MeV and 100keV beams.

In this report, a preliminary solution permitting beam transport only of 100keV beams is used. The existing experimental area layout will here be retained which is an advantage for the AD experiments. The beamlines will be modified using electrostatic deflectors and quadrupole triplets and can be shielded with dual concentric layers of mu-metal wherever necessary. As much as possible of existing vacuum equipment etc. will be re-used. A rough estimate is given in Table 33.

Ejection lines	Qty	Price/unit (kCHF)	Cost (kCHF)	Manpower FTE (MY)
Quadrupole triplets	13	35	455	1.0
Dipolar deflectors	4	50	200	
Power supplies/cabling	104	2.3	240	
Controls				
Vacuum chamber modifications			500	2.0
Total			1395	3.0

Table 33. **Ejection lines resources**

Instrumentation

Non-destructive photocathode microwire beam profile monitors have been developed and are used by the ASCUSA collaboration, these would suit the new beamlines well.

Beam profile monitor specifications:

Number of detectors:	15 devices
Energy range:	10 keV to 20 MeV
Aperture:	60 x 60 mm
Active area:	48 x 48 mm
Spatial resolution:	1 mm or 1.5 mm
Dynamic range:	10000
Channels:	64 channels parallel readout
Sensitivity:	1e6 antiprotons in a 300-ns-long bunch
Transmission:	1-2% losses per detector.
Vacuum:	<1e-10 mb

Remotely controllable and readout is possible through the net.

Beam profile monitors	Cost/unit (kCHF)	Total cost/15 units (kCHF)
Vacuum chamber, UHV with 128 readout pins on ceramic bakeable to 200 degrees C, compatible to 1e-10 mb.	22,000	330,000
Electronics, CMOS parallel 64 channels, serial readout bonded on the above detector	25,600	384,000
Microwire electrodes, 32 x 32 mm 1 micron diameter on thick-film printed ceramic UHV board.	4,000 *2 (H+V)	120,000
Power supply +/- 15 V and +/- 5 V	400	6,000
Power supply - 100V, remote cabling and biasing	500	7,500
Cabling etc.	included	
Total	56,500	847,500

Table 34. **BPM resources**

Delivery time: 2 years from the date of order, including tests. Discussions are underway whether manpower could be supplied by the ASACUSA collaboration

Resource Estimate Summary

Ejection lines	Material (kCHF)	Manpower FTE (MY)
Electrostatic elements + beamline modifications	1395	3.0
Profile monitors	850	*
Total	2245	3.0

(*) Manpower could be provided by the ASACUSA collaboration

Table 35. **Exp. Area beamline resources**

15. Drawings and mechanical design

A global estimate for all work related to mechanical design and drawings has been made. Included are all ELENA items including injection and ejection lines.

Resource Estimate Summary

Design/drawings	Material (kCHF)	Manpower FSU or CERN (MY)
Total	NA	17

Table 36. **Design and drawings resources**

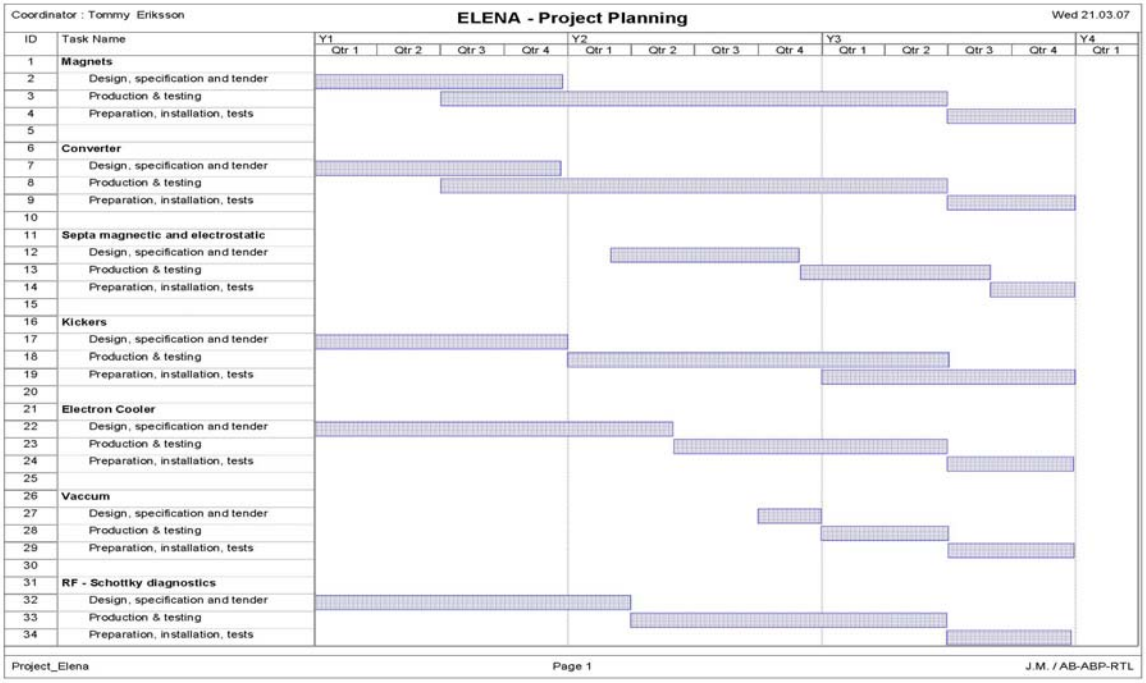
16. General items, Infrastructure, cooling water, electricity

Resource Estimate Summary

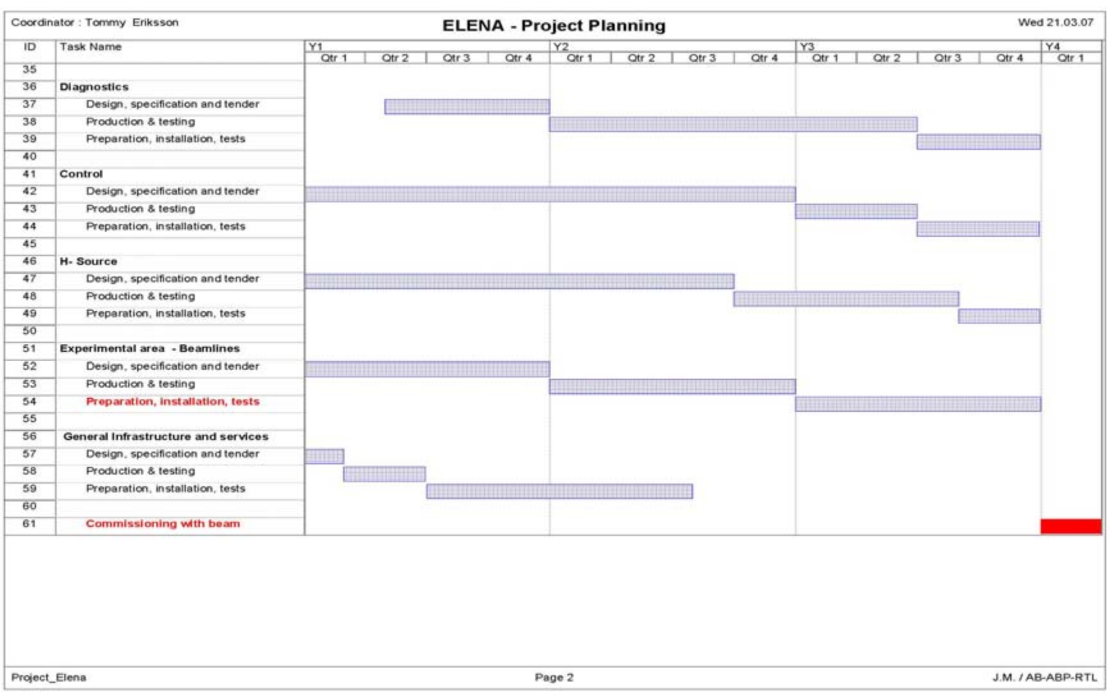
Design study + general	Material (kCHF)	Manpower FTE (MY)
Design study		5
Coordination		1.5
Electricity distribution	100	
Cooling water distribution	100	
Concrete shielding + access door	40	
Div.	50	
Total	290	6.5

Table 37. General items resources

17. Planning



Coordinator : Tommy Eriksson
ELENA - Project Planning
Wed 21.03.07
ID
Task Name
Y1
Y2
Y3
Y4
Qtr 1
Qtr 2
Qtr 3
Qtr 4
1 Magnets
2 Design, specification and tender
3 Production & testing
4 Preparation, installation, tests
5
6 Converter
7 Design, specification and tender
8 Production & testing
9 Preparation, installation, tests
10
11 Septa magnectic and electrostatic
12 Design, specification and tender
13 Production & testing
14 Preparation, installation, tests
15
16 Kickers
17 Design, specification and tender
18 Production & testing
19 Preparation, installation, tests
20
21 Electron Cooler
22 Design, specification and tender
23 Production & testing
24 Preparation, installation, tests
25
26 Vaccum
27 Design, specification and tender
28 Production & testing
29 Preparation, installation, tests
30
31 RF - Schottky diagnostics
32 Design, specification and tender
33 Production & testing
34 Preparation, installation, tests
Project_Elena
Page 1
J.M. / AB-ABP-RTL



Coordinator : Tommy Eriksson
ELENA - Project Planning
Wed 21.03.07
ID
Task Name
Y1
Y2
Y3
Y4
Qtr 1
Qtr 2
Qtr 3
Qtr 4
35
36 Diagnostics
37 Design, specification and tender
38 Production & testing
39 Preparation, installation, tests
40
41 Control
42 Design, specification and tender
43 Production & testing
44 Preparation, installation, tests
45
46 H- Source
47 Design, specification and tender
48 Production & testing
49 Preparation, installation, tests
50
51 Experimental area - Beamlines
52 Design, specification and tender
53 Production & testing
54 Preparation, installation, tests
55
56 General Infrastructure and services
57 Design, specification and tender
58 Production & testing
59 Preparation, installation, tests
60
61 Commissioning with beam
Project_Elena
Page 2
J.M. / AB-ABP-RTL

18. Conclusion

Despite the fact that much information is missing at this stage, this report tries to give an estimate of the cost and manpower needs for design and construction of ELENA [Table 38]. This estimate is likely to change as the design study progresses. It is worth noting that ELENA is a new machine with most items (ring, experimental area, electron cooler, use of H- source etc.) designed from scratch and thereby causing considerate construction costs.

Item	**Material (kCHF)**	**Manpower FSU (kCHF)**	**Manpower FTE (MY)**
Magnets (ring+inj. line)	**885**	**160**	**3.2**
Power converters	**857**		**1.5**
Injection/ejection septa	**220**		**2.9**
Injection/ejection kickers	**830**		**4.8**
Electron cooler	**1350**		**6.5**
Vacuum	**1175**	**27**	**5.0**
RF + Schottky diagnostics	**303**	**10**	**3.3**
B-trains	**80**		**0.7**
Diagnostics	**620**	**85**	**2.4**
Controls	**682**		**0.7**
H- source	**400**		**0.5**
Experimental area	**2245**		**3.0**
Mech. Design/Drawings			**17.0**
Div.	**290**		**6.5**
Total (MCHF/MY)	**9.937**	**.282**	**58.0**
Grand Total (MCHF/MY)	**10.219**		**58.0**

Table 38. **ELENA cost estimate**

References

[1] H. Herr,*Proceedings of the Workshop on Physics at LEAR with Low-Energy Cooled Antiprotons, Erice*, 1982, eds. U. Gastaldi and R. Klapisch (Plenum Press, New York and London, 1984), p. 633.
[2] C. Gonzalez and F. Pedersen, An Ultra Low Noise AC Beam Transformer for Deceleration and Diagnostics of Low Intensity Beams, PAC 99
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